Electron Energy Spectrum of the West Lobe of Fornax A from a Hard X-ray Observation with Suzaku

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ABSTRACT

Suzaku Hard X-ray observation of the archetypical X-ray emitting radio lobe object Fornax A (NGC 1316) is reported. The results firstly revealed a non-thermal X-ray spectrum up to 20 keV from the lobe, and showed that a single component of non-relativistic electron with an energy distribution over a two order of magnitudes generates both the X-ray and radio emissions. On the basis of observations made with Suzaku, the present paper shows that a 0.7 – 20 keV spectrum is well described by a single power-law model with an energy index of 0.68 and a flux density of 0.12 ± 0.01 nJy at 1 keV from the West lobe. Utilizing published radio data, the multiwavelength spectrum shows an undoubtable single electron energy, distribution over a Lorentz factor $\gamma = 300 - 90000$, generating both the X-ray and radio emissions.

KEY WORDS: Active Galactic Nucleus: Radio Galaxy — Radio Lobe — Hard X-ray Observation

1. Introduction

The radio lobe object Fornax A is the first object from which cosmic microwave background (CMB) boosted inverse-Compton (IC) lobe X-rays are detected (Feigelson et al. 1995; Kaneda et al. 1995: K95 hereafter). Following the discovery, a number of radio lobes have been observed to reveal electron and magnetic energy densities in the lobes (e.g. Isobe et al. 2006: I06 hereafter), including Fornax A itself (Tashiro et al. 2001:T01 hereafter; Kim & Fabianno 2003; I06). Although all of these analysis assumed a single energy distribution of the relativistic electrons in the lobes, it is estimated that the observed synchrotron radio emissions are produced by electrons whose Lorentz factor of $\gamma = 4000 - 60000$ while the observed inverse-Compton X-rays below 10 keV are produced by electrons of $\gamma = 1000 - 3000$. This energy gap between the two observation bands leaves rooms of discrepancy between synchrotron electrons and inverse-Compton electrons. One is a possible spatial distribution discrepancy and the other is a possibility of a break or cut off between the two energy range of electrons. Only a hard X-ray observation above 10 keV fills the gap. Utilizing the hard X-ray detector (HXD) on board Suzaku, we observed the archetypical radio lobe object Fornax A and succeeded to observe 0.7 to 20 keV spectrum. Detailed description is presented in Tashiro et al. (2009).

2. Observation and Results

Suzaku observations of the Fornax A West lobe were performed between 2005 December 23 20:51 UT and December 26 14:40. Since the field of view of the HXD is so wide that it covers the host galaxy in the same field of view, we also performed offset observation pointing at the host galaxy in order to evaluate the X-ray contamination from the host galaxy and the non-X-ray background (NXB). The HXD and XIS were operated in nominal mode throughout the observations.

The entire XIS field of view of $18' \times 18'$ is covered with the extended emission. As previously reported by T01, the lobe X-ray emission extends up to $12'$ in radius, which fills the entire radio lobe region. In the following analysis, we set the circle data acquisition region with a radius of $7.'25$ according to previous works (K95; T01).

Background subtraction is the key in the HXD data reduction procedure. Here we employed model backgrounds of NXB (Fukazawa et al. 2007) and CXB (Bolt et al. 1987) for the HXD data, after confirming that it is consistent with those spectra obtained from the offset observation or from the earth occulted time regions.

Thus we obtained the background-subtracted spectra from the XISs and HXD through 0.7 – 20 keV. After evaluating thermal emissions from surrounding gas, we introduced the spectral slope determined by radio observation, and evaluated the XIS-HXD/PIN spectrum.
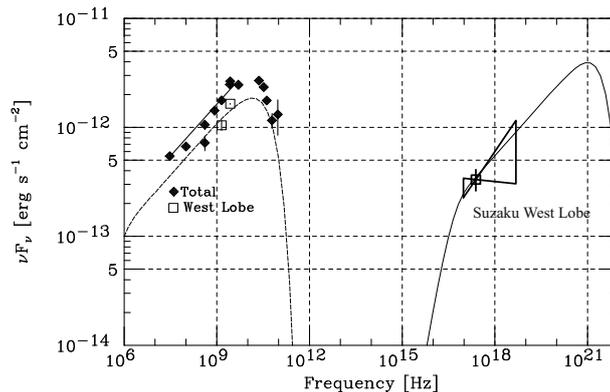
Fig. 1. Spectral energy distribution from the West lobe (open squares) and total (filled diamonds). Derived models for the synchrotron emission (dashed line) and the CMB-boosted IC emissions (solid line) are shown with lines (see Tashiro et al. 2009 and references therein).

We obtained the best fit X-ray flux density at 1 keV of 0.12 ± 0.01 nJy, with an energy index of 0.68 (fixed), and confirmed that the newly obtained fitting parameters are consistent with those presented in previous reports (K95; T01) Note that we showed only the nominal tuned-NXB subtracted HXD/PIN spectrum above as the most conservative case. However we also confirmed that there was no significant difference in the obtained best fit parameters whether we employed the nominal or rescaled NXB.

3. Discussion and Conclusion

Employing the derived power law component for the diffuse hard X-rays, we plotted the spectral energy distribution (SED) together with the radio spectra in figure 1.

An X-ray spectrum following a single power law distribution, which does not smoothly connect to the synchrotron component, requires another origin. The IC process is the most promising origin for the observed hard X-rays reported so far. In accordance with Harris and Grindlay (1979), we derived the estimated energy density of the electrons and the magnetic field energy density to be $u_{\mathrm{e}} = (5.1 \pm 1.0) \times 10^{-13}\mathrm{erg\ cm}^{-3}$ and $u_{\mathrm{m}} = (0.67 \pm 0.08)\eta^{-1} \times 10^{-13}\mathrm{erg\ cm}^{-3}$, respectively, where η is the filling factor of magnetic field against the electron spatial distribution. Here, we assumed an electron Lorentz factor of $\gamma = 300 - 90000$, as we describe below, and included the systematic errors arising from the ambiguity of the reported radio flux and slope according to § 4 in I06. Adopting the above values, we calculated the CMB boosted IC spectrum and plotted the results in the obtained SED in figure 1. We assumed an electron differential energy spectrum with a single power law distribution of

$$N_\gamma = 2.0 \times 10^{-6}\gamma^{-2.36} \text{ electrons cm}^{-3},$$

with the lower boundary electron energy distribution of $\gamma = 300$ to describe the lower energy end of the detected X-rays. Similarly, we set the upper boundary of $\gamma = 90000$ in accordance with the higher end of the radio observation of the total lobe observations. The calculation program was written to use the SSC equations presented in Kataoka (2000), to which we added the CMB/IC spectrum, and it can be seen that it provides a good description of the obtained multiwavelength data.

The electron Lorentz factor of $\gamma = 300 - 4000$ is required by the CMB/IC X-ray spectrum in the range of 0.7 – 20 keV, where we employed the nominal (or rescaled) NXB model for the HXD/PIN. At the same time, adopting the derived magnetic field, the observed synchrotron radiation spectrum requires a Lorentz factor of $\gamma > 4200$. Thus, we conclude that a single electron energy distribution can naturally explain the two independent measurements in radio and X-ray bands. We also note that the derived electron and magnetic field energy densities are not only consistent with those determined in previous reports (T01) but are also in very good agreement with those determined for the East lobe (I06).

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